d-REBAR

Fig 1: The two configurations for *d*-REBAR

YieldPoint's *d*-REBAR allows engineers, technicians, consultants and contractors to monitor how the strain or load develops along rigid bolts, such as resin rebar, and hence to assess the Factor of Safety against steel rupture. The technology is applicable to rebar elements, threaded bolts, and a variety of other steel elements used in mining, civil and construction projects. It has the potential to predict the risk of catastrophic structural failure: in fact *d*-REBAR monitoring can enhance many aspects of *engineering design*, *installation quality control*, *long-term operational assessment,* and *rehabilitation*.

The physical instrumentation of the *d*-REBAR is recessed into a 3.2mm wide groove which is milled into the steel bolt. The instrumentation consists of up to six (6) axially configured long base-length strain gauges (300-2000mm length). The strain gauges are encapsulated within an epoxy resin and are designed to withstand the rigors of bolt installation using standard procedure. The electronics for the *d*-REBAR are housed in a stainless steel tube extending 100mm from the head of the bolt (Fig 1).

Features:

▲ *Instrumented rebar that can be spun in resin*

▲ *Available with 2 to 6 strain gauges in two diametrically opposed slotted channels.*

▲ *Readout head encapsulated in stainless steel tube for protection.*

▲ *Microcontroller provides output directly in mm.*

▲ *Each bolt is individually calibrated.*

▲ *Immunity to hostile environment*

▲ *High survivability to shock and vibration*

▲ *Easy to install and maintain*

▲ *Low cost peripheral devices for data-logging (Blu_Logger) and data upload using TCP/IP (DESTINY)*

▲ *Competitively priced*

d-REBAR

Technology

How does it work?

The **d_REBAR** is based on a miniature long baselength inductive strain gauge, small enough to be recessed into a 3.2mm groove in the bolt.

What is an inductive strain gauge?

A miniature inductive displacement sensor comprising a precision coil and a high permeability core attached to stainless steel rod. The ends of the displacement sensor are secured to the bolt at a specified distance apart referred to as the baselength (BL). This baselength may vary between 300mm and 2000mm so comprising a long baselength strain gauge.

Upon loading, stretch of the bolt causes displacement of the precision coil relative to its high permeability core. The corresponding change in coil inductance causes a variation in the frequency of a resonant electrical circuit which is measured by the microcontroller in the instrument head. The accuracy of the displacement sensor is enhanced by an empirically derived temperature compensation algorithm that is applied by the microcontroller.

Individual Calibration

Every instrument is subjected to a multipoint calibration. The calibration coefficients are written into microcontroller memory, and a piecewise linear function is used to enhance linearity the output signal and applied strain.

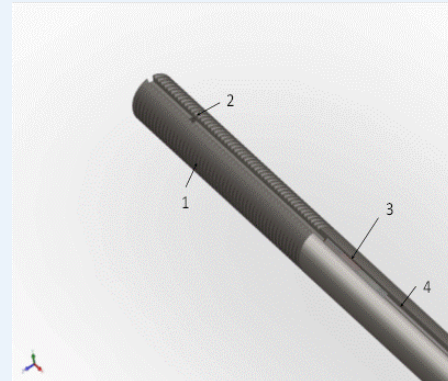Every instrument is provided with a calibration report.

Telemetry

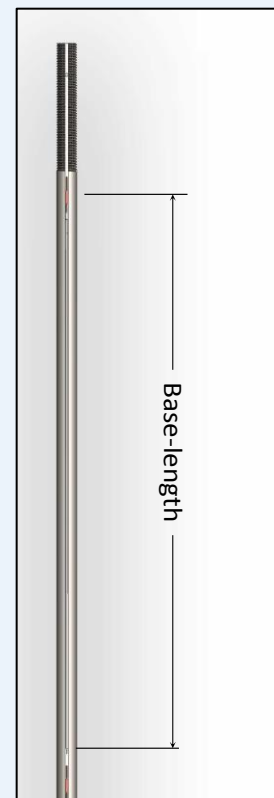**Fig 2.** Both ends of the inductive strain gauge are positioned within the 3.2mm groove.

Base-length

Fig 3: The baselength (B**L**) is the distance between the ends of the gauge which are attached to the rebar.

Calibration

APPLIED DISP (mm)	DISP 1 (mm)	DISP 2 (mm)	DISP 3 (mm)	DISP 4 (mm)	DISP 5 (mm)	DISP 6 (mm)
0.00	.004	.000	.010	.007	.000	.005
1.00	1.007	1.001	1.009	1.008	1.000	1.004
2.00	2.004	2.002	2.010	2.006	2.003	2.004
3.00	3.004	3.002	3.007	3.007	3.003	3.002
4.00	4.003	4.002	4.004	4.006	4.000	4.002
5.00	5.004	5.001	5.005	5.007	5.001	5.001
6.00	6.003	5.998	6.007	6.004	5.999	6.004
7.00	7.007	6.997	7.008	7.008	6.998	7.004
8.00	8.003	7.999	8.008	8.005	8.000	8.005
9.00	9.005	8.996	9.004	9.008	8.999	9.004
10.00	10.000	10.000	10.006	10.003	10.001	10.005
11.00	11.003	11.000	11.005	11.004	10.998	11.003
12.00	12.000	12.003	12.005	12.002	12.004	12.003
13.00	13.006	12.997	13.006	13.006	12.997	13.005
CAL. SLOPE	0.9998	0.9998	0.9997	0.9997	0.9999	1.0001
CAL. OFFSET	0.0049	0.0011	0.0087	0.0075	0.0011	0.0033
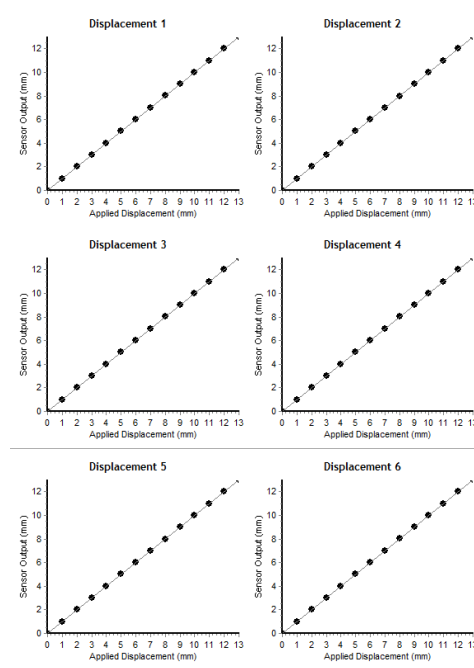
Calibrated by: Reza

Fig. 4: Calibration sheet for a typical *d⁶*REBAR.

The d_REBAR mk II is calibrated directly in mm with 1mm resolution. The range is 13mm. The corresponding strain, $\varepsilon(t)$, is:

$$\varepsilon(t) = \frac{u(t) - u(t=0)}{L}$$

where $u(t)$ is the is the current displacement value, $u(t=0)$ is the initial displacement value and L is strain gauge base-length.

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Configuration

d-REBAR technology can be applied to any rigid bolt or bar. Either a pair of strain gauges (for end anchored bolts spun in resin) or an array of loadmeters can be specified. For applications which require enhanced axial load resolution the strain gauge array should be *staggered* (Fig4 upper). If bending moments need to be more accurately resolved then a *stacked* configuration may be preferable (Fig 4. lower). A theoretical comparison of both is presented in a related technical note.

The specification of the strain gauge locations should be based on an understanding of the load distribution along a fully grouted rock bolt. The upper plot in Fig. 5 shows a typical load distribution. At the collar of the borehole the load depends on the stiffness (i.e. bearing conditions) of the faceplate. Along the length of the bolt the load increases in the bolt along the "pick-up" length and reaches a peak at the neutral point. The load decreases along the remainder of the bolt length, the "anchor length", and is zero at the free end. In the case of a stiff bearing surface for the plate and a rapid decrease in the displacement magnitude around the excavation then the neutral point may actually occur at the faceplate (Fig 5, lower plot).
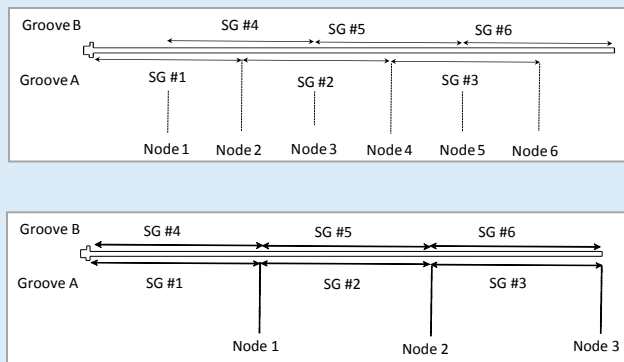

Fig 4. *d⁶*REBAR Staggered (upper) and stacked (lower) strain gauge configurations. Gauges 1 and 4 are closest to the head.
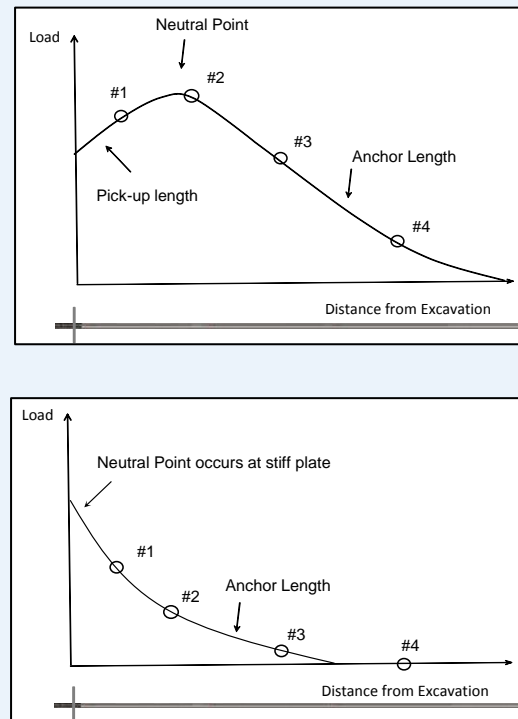
Theoretical Load Distribution

Fig. 5. Axial load distribution along fully grouted bolts . Lower plot is for a more rigid plate.

Figure 5 assumes that the bolt is loaded by ground movement vectors that are co-axial with the bolt. Non-axial or shear movements can result in more complex load distribution. In this case the measurement of bending moments in the bolt cannot be absolutely measured but gauges on opposite sides of the bolt can provide compensation. The long base-length strain gauges are best suited for axial measurement.

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Installation

The **d-REBAR** has been specifically designed to be spun in epoxy resin using a rock drill. The electronics head can be either (i) detachable from the bolt during installation or (ii) attached to the end of the bolt so that the hole assembly is encapsulated (Fig. 1). The first option results in an easier installation procedure but care must be taken to properly seal the end connector in wet conditions.

Leadwires

The leadwire comprises 2 twisted pairs: (i) power (6-24Vdc) and (ii) RS485 differential signal. 10m of additional leadwire is provided with each instrument at no additional cost.

Installation precautions

Installing instrumentation with a rock drill can be challenging even for the toughest design. Care must be taken to ensure that the drill is well aligned with the borehole.

Initial bending

Depending on the type or bolt, the installation process and the angle of installation, considerable bending can be generated during the installation process.
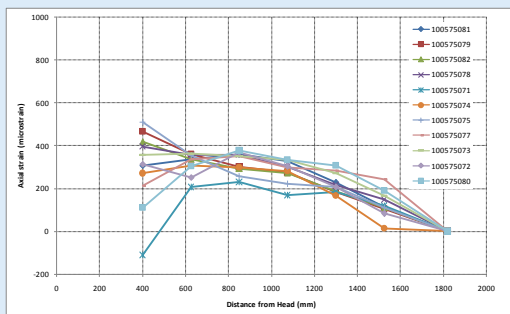

Fig 6. Bolt loads immediately after installation

Results

Manual Readout

Fig. 7. The *d*-Reader

Readout can be made using YieldPoint's low cost manual readout box (**d-READER**), which displays the Sensor ID the SensorType , and the Temperature and strain data in ^{o}C and $\mu\varepsilon$.

Data-logging

Data from **d-REBAR** can be collected using YieldPoint's **Blu**LOGGER data-loggers (**Blu**LOGGER). The Logger can store up to 30,000 reading from (i) 4 wired loggers and (ii) up to 24 Bluetooth 5 instruments. Two option exist for download (i) USB and (ii) Bluetooth using a tablet. The loggers require no configuration and are fully interchangeable with any other type of YieldPoint instrument (**d-MPBX** borehole extensometers, **d-GMM**'s, **d-TILT/ BluTilt** tilt-meters, **BluWire** interface *etc*.). Therefore clusters of instruments monitoring bolt load and ground movement can be easily implemented.

d-REBAR

Telemetry

BluPoint Telemetry

Instruments can be wirelessly enabled using BluLink which provides a Bluetooth 5.0 connection which has a range of 100m LOS. BluLink can transmit data to BluGateways which are WiFi or LTE-M enabled. These devices can upload data to VantagePoint, YieldPoint's data aggregation and visualization tool.

BluLink also functions as a local data-logger storing 30,000 readings. Wireless download can be by any Bluetooth enabled Android device using the BluPoint app.
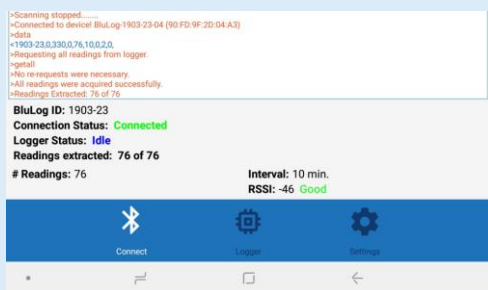

Fig. 8. Blulink and the BluPoint app.

Fig. 9. The BluLogger app.

Telemetry

900MHz 1for1 Telemetry

For longer range deployments the d-Rebar operate with YieldPoint's 900MHz 1for1 mesh radio telemetry system. Individual radios have a LOS range of 300m.

Fig 10: An installed 1 for radio

Fig 11: The 1for1 Gateway

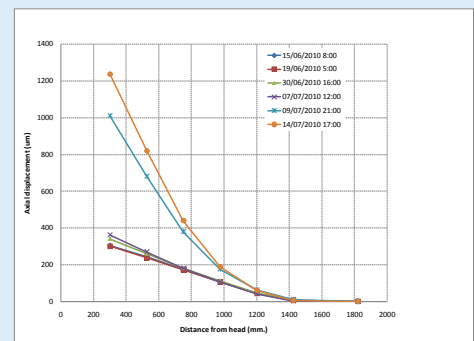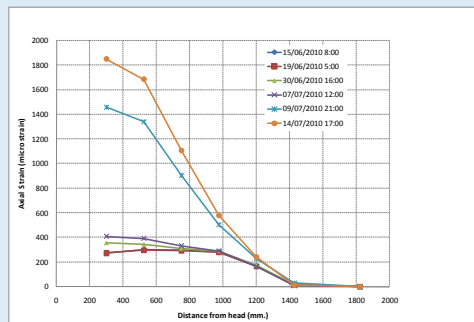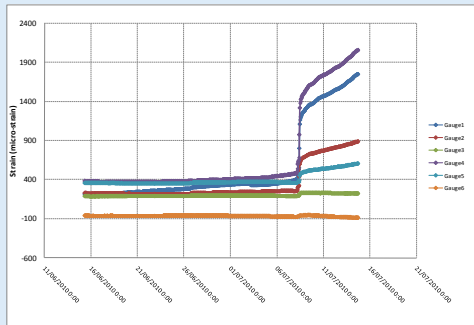# d-REBAR

Data Analysis

Fig. 12 Data from a d^6REBAR: (top) strain *versus* time (middle) axial strain versus length and displacement versus length. The data was collected with a *d*-LOGGER

Load versus Strain

The load can be determined based on the rebar manufacturer's load/strain curves mill test certificate. A typical result is shown in Figure 9. The load/strain profile is linear up to around 2500$\mu\varepsilon$ at which point the steel reaches its yield point and enters a perfect plastic phase, which after more than 1% strain is followed by strain-hardening and eventual rupture.
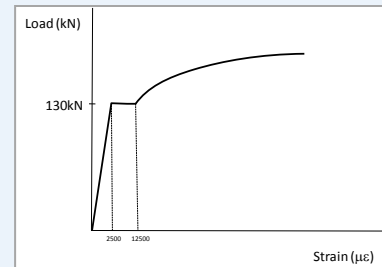
Data Interpretation

Fig.9. The load versus strain profile for a typical # 7 rebar.

The protracted non-linear behavior explains why data from the d-REBAR is provided in $\mu\varepsilon$ as opposed to load. The *d*-REBAR's long base-length strain gauges have the capability to follow deformation up to 5.0% which is considerably higher than a foil resistance strain gauge (>0.5% strain typ.).

d-Rebar arrays

The strain distribution for resin rebars can be dramatically influenced by discrete failure zones in the rock. To delineate these structures a clustered array of *d*-Rebar bolts can be effective as shown below.
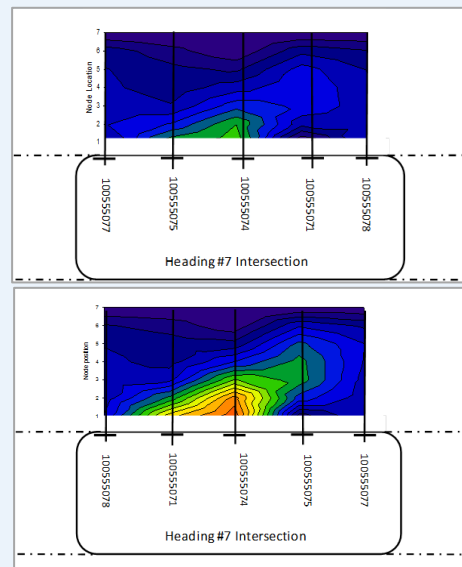

Fig 13: An array of 10 d^6REBAR with staggered gauges delineating an asymmetric fracture zone above an intersection (max load is 1500$\mu\varepsilon$ or 10tons)

d-REBAR

Applications

The **d-REBAR** is designed to be a user-friendly rock bolt monitoring solution that will enhance safety and improve support design. It can be routinely deployed within the production environment.

- ▲ Monitoring rock bolt loads in tunnels, drifts and roadways.

- ▲ Intersections

- ▲ Monitoring bolt reinforcement in stopes and other large openings

- ▲ Monitoring support elements in shafts.

Specification

- ▲ **Core Technology:** Temperature compensated inductive disp. sensor configured as a strain gauge. User specified base-length. Digital Temperature sensor

- ▲ **Output Signal:** RS485 with transmission up to 500m over 2 x tp.

- ▲ **Disp Range (F.S):** 13-20mm.

- ▲ **Disp Resolution:** 0.001mm.

- ▲ **Disp Linearity:** typically 0.1mm

- ▲ **Strain Range (F.S. for 500mm Gauge length):** 0-26,000$\mu\varepsilon$.

- ▲ **Equiv. Load Accuracy** – typically better than +/- 0.5ton.

- ▲ **Temp. range:** Temp: -40 to 125°C

- ▲ **Temp Resolution:** 0.1^{o}C

- ▲ **Temp Accuracy:** +/- 2°C Temp

- ▲ **Temp. coeff for disp sensor:**

  <+/- 0.01%FS / ^{o}C

To Order Specify:

- ▲ Configuration(Attached/ Detached).

- ▲ Number of strain gauges(1-6).

- ▲ End Locations of gauges.

- ▲ Leadwire length.

- ▲ Poly leadwire cover.

YieldPoint